Investment Networks, Sectoral Comovement, and the Changing U.S. Business Cycle

Christian Von Lehn   Thomas Winberry

Discussion: Lilia Maliar

Was machen sie in Artikel?

- By paper, I mean a composite of a previous version of the paper (henceforth, LW, 2019) and slides presented today.
- *Motivation:* explain RBC patterns in two subperiods
  – before 1984
  – after 1984.
- Nonstationary aggregate patterns of interest:

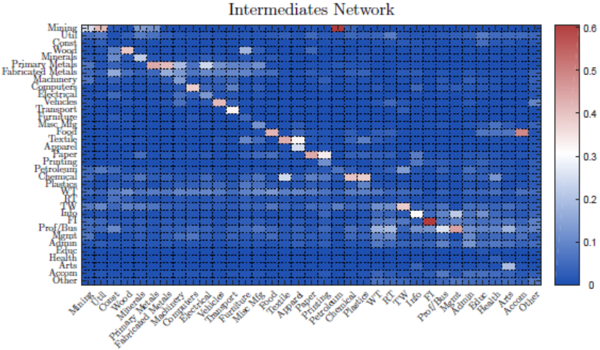
	before 1984	**after 1984**	**change**
labor productivity	higly procyclical	roughly acyclical	$\downarrow$ by 60%
output	more volatile	less volatile	$\downarrow$ by 40%

$\Longrightarrow$ Relative volatility of labor to that of output $\uparrow$ by 34%.

- Also, volatility of agg. investment relative to output increased in post-1984 period.
- *Idea:* to relate these nonstationary RBC patterns to sectoral comovements.

Was machen sie in Artikel? (cont.)

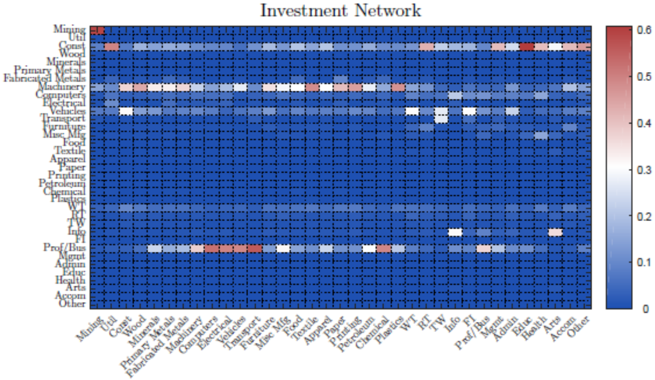
- Model with linkages in intermediate goods and investment goods across manufacturing sectors (35 in total).
- The industries receive/provide the intermediate goods and services from/to other sectors:



BEA I-O databases 1947-2017

Was machen sie in Artikel? (cont.)

- Production of investment goods is concentrated in a small number of sectors – "investment hubs", IH.
- LW (2019): an IH comprises at least 10% of the investment goods in a different sector.



BEA capital flows (1997) plus fixed assets 1947-2017

Was machen sie in Artikel? (cont.)

Propagation of "investment hub shocks"

- Let NH = non-hub sector
- Productivity in NH $\uparrow$
  - Value added of NH $\uparrow$
  - Employment of NH $\uparrow$
  - Demand for investment in NH $\uparrow$
  - This increase in investment demand must be met by IHs
  - IHs $\uparrow$ their demands for other sectors' intermediate goods
  - Employment $\uparrow$ in all sectors
- Thus, employment is driven by "investment-hub shocks".

Was machen sie in Artikel? (cont.)

- Within-sector patterns are stationary:

	before 1984	**after 1984**	**change**
labor productivity	procyclical	procyclical	0%
output	highly volatile	less volatile	$\downarrow$ by 16%

$\Longrightarrow$ Relative volatility of labor to that of output did not change.

- Driving forces at the sector level:

	before 1984	**after 1984**
value added	aggregate TFP shocks	sector-level TFP shocks
employment	aggregate TFP shocks	investment-hub shocks

Comment 1: Why a multisector model?

- LW (2019) motivate their work by the basic RBC facts:
  – labor productivity is highly procyclical in pre-1984 and roughly acyclical in post-1984 years.
- Using the multisector RBC model, LW (2019) show that sectoral heterogeneity matters for agg. dynamics.
- Why was consumer heterogeneity discarded, as a possible mechanism?
  – in a RA, $corr\left(\frac{y}{n}, n\right) = 1$.
- Maliar and Maliar (2001, JEDC):
  – a HA version of the optimal growth model.

	$\gamma = \frac{3}{2}$ $\sigma = 1$	$\gamma = 1$ $\sigma = 1$	$\gamma = \frac{3}{5}$ $\sigma = \frac{1}{3}$	$\gamma = \frac{3}{5}$ $\sigma = \frac{1}{5}$	$\gamma = \frac{3}{5}$ $\sigma = \frac{3}{20}$	U.S.
σ_n	0.51	0.70	1.65	1.85	2.01	1.66
$\sigma_{y/n}$	0.78	0.69	0.25	0.23	025	1.18
$\rho_{\frac{y}{n},y}$	0.99	0.98	0.59	0.17	-0,17	0.42

LW's (2019) methodology

1. Solutions are found by **linearization.**
   – Volatility of sector-specific shocks does not affect solutions.
2. Consider just **2 subperiods**: before 1984 and after 1984.
   – What is magic about 1984?
   – How are two solutions (for two subperiods) are put together?
3. All parameters other than shocks are **constant** over time:
   – E.g., intermediate and investment I-O networks are averages across 1947-2017.
   – Covariance matrix Σ_τ in the process for the sector-specific TFP,

$$\log A_{jt+1} = \rho_j \log A_{jt} + \varepsilon_{jt+1}, \qquad \varepsilon_{jt+1} \sim \mathcal{N}\left(0, \Sigma_\tau\right),$$

   differs in two subperiods, $\Sigma_\tau = \left(\Sigma_{pre-1984}, \Sigma_{post-1984}\right)$.

Comment 2: Why are there just two subperiods?

- It would be natural that these periods (pre-1984 and post-1984) were not fixed.
- Instead, there is a process for each parameter that changes over time.
- There is evidence in the literature on time-changes in
  – depreciation rate δ_j;
  – labor share $1 - \alpha_j$;
  – volatlity of sector-specific shocks.
- Other parameters that they can make time-dependent in their model:
  – value-added shares θ_j;
  – intermediate I-O network Γ_{ij};
  – investment I-O network Λ_{ij};
  – consumption shares ξ_j.
- Now they are computed as averages over 1947-2017 (the benchmark model) or as averages in 2 subperiods.

Comment 2: Why are there just two subperiods?

- Traditionally, RBC facts are explained by stationary RBC models.
- LW (2019) document many non-stationary patterns and use a stationary model to account for them.
- Why to use a stationary model to explain non-stationary patterns?
- I want to show the methodology that
  – characterizes the solutions that change over time;
  – solves non-linearly.
- My presentation is based on the paper "Tractable Framework for Analyzing a Class of Nonstationary Markov Models" (joint with S. Maliar, J. Taylor and I. Tsener).
- Publicly provided code: "*EFP_MMTT_2015.zip" - Extended Function Path (EFP) method for time-dependent models.*
- Computes an accurate solution to a test-model with labor augmenting technological progress and balanced growth using a transformation to stationary model.
- Computes an EFP solution to a nonstationary test model directly, without using the property of balanced growth.

Motivation: Why nonstationary models?

Unbalanced growth in the U.S. data

- Growth patterns appear to be highly unbalanced. For example, over the 1963-1992 period (Krusell, Ohanian, Ríos-Rull, Violante 2000):
  – output and the stock of structures increased by a factor of two;
  – the stock of equipment increased by more than seven times;
  – the number of unskilled workers slightly decreased;
  – the number of skilled workers nearly doubled;
  – the price of equipment relative to consumption (structures) went down by more than four times;
  – the skill premium was roughly stationary.
- Moreover, the growth rates are not constant over time.
- *Question:* "Can a general-equilibrium macroeconomic model (e.g. with capital-skill complementarity) explain such unbalanced growth patterns?"
- *To answer*, one may need **a framework for analyzing nonstationary and unbalanced growth models**.

Motivation: Why nonstationary models? (cont.)

Other examples of nonstationary applications

- deterministic trends in the data (population growth, climate changes, etc.);
- different kinds of technological progress that augment productivity of different factors, e.g., directed technical change;
- an entry into a monetary union;
- nonrecurrent policy regime switches;
- deterministic seasonals;
- changes in the consumer's tastes and habits.

In such models, the optimal value and/or decision functions nontrivially change from one period to another.

A nonstationary growth model

We now introduce nonstationary Markov environment into dynamic general equilibrium modeling paradigm:

$$\max_{\{c_t, k_{t+1}\}_{t=0}^{\infty}} E_0 \left[\sum_{t=0}^{\infty} \beta^t u_t(c_t) \right] \quad (1)$$

$$\text{s.t. } c_t + k_{t+1} = (1-\delta) k_t + f_t(k_t, z_t), \quad (2)$$

$$z_{t+1} = \rho_t z_t + \sigma_t \varepsilon_{t+1}, \qquad \varepsilon_{t+1} \sim \mathcal{N}(0,1), \quad (3)$$

– sequence of u_t, f_t and φ_t for $t \geq 0$ is known to the agent in period $t = 0$; ε_{t+1} is i.i.d;

– $\rho_t \in (-1, 1)$ and $\sigma_t \in (0, \infty)$ are given at $t = 0$.

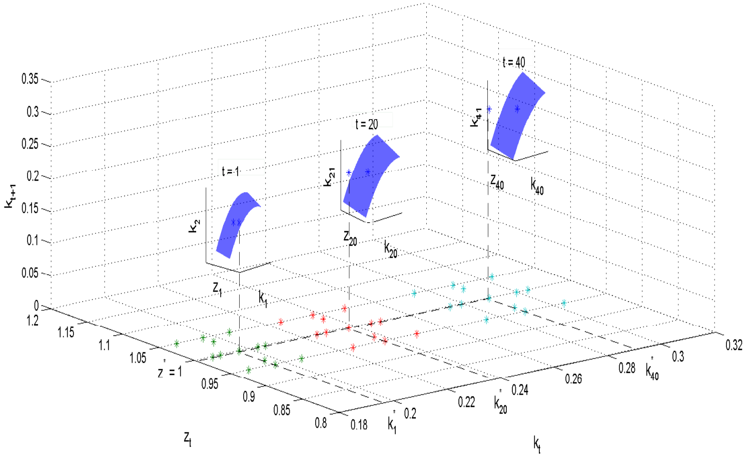
- The conditional distribution $z_{t+1} \sim \mathcal{N}(\rho_t \overline{z}_t, \sigma_t^2)$ depends only on the most recent past $z_t = \overline{z}_t$ and is independent of history $(z_t, ..., z_0)$. $\Longrightarrow$ *The process is Markov.*
- Since ρ_t and σ_t change over time, the conditional probability distribution $\mathcal{N}(\rho_t \overline{z}_t, \sigma_t)$ depends not only on state $z_t = \overline{z}_t$ but also on a specific period t. $\Longrightarrow$ *The transitions are nonstationary.*

Introducing extended function path (EFP) framework

Extended function path (EFP) framework includes two steps.

- **Solving a T-period stationary economy:** Assume that in a very remote period T, the economy becomes stationary, i.e., the utility and production functions and the laws of motions for exogenous shocks are time invariant, i.e., $u_t = u$, $f_t = f$, $\rho_t = \rho$ and $\sigma_t = \sigma$ for all $t \geq T$:
$\Rightarrow$ we *can solve for equilibrium using conventional methods for stationary models.*
- **Constructing a function path:** Using the T-period solution as terminal condition, iterate backward on optimality conditions to construct a sequence (path) of time-dependent value and decision functions $(V_0(\cdot), V_1(\cdot), ...)$ and/or $(K_0(\cdot), K_1(\cdot), ...)$.
$\Rightarrow$ *this is like solving OLG models.*

Example of function path constructed by EFP



Theoretical foundations of EFP framework

We provide theoretical foundations of the extended function path framework.

We prove two theorems:

- **Theorem 1 (existence)**: EFP approximations exists, is unique and possess a Markov structure.
- **Theorem 2 (turnpike)**: EFP can approximate a time-dependent solution to a nonstationary Markov model with an arbitrary degree of precision as the time horizon T increases.

Turnpike theorem

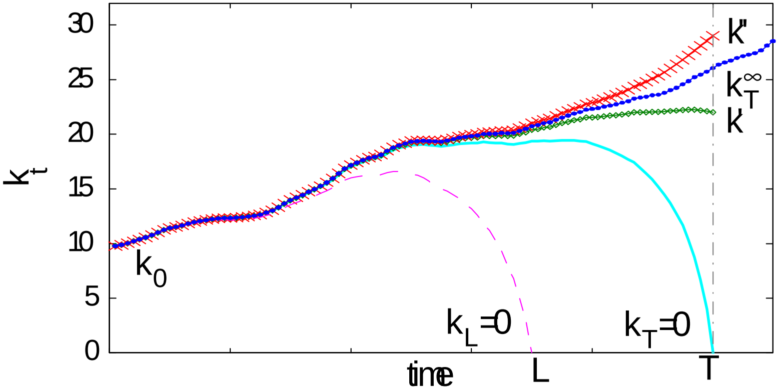
Turnpike ≡ highway.

Turnpike theorem

- *Turnpike theorems*: turnpike is often the fastest route between two points which are far apart even if it is not a direct shortest route.
- Example: Driving from Los Angeles to San Francisco on highway 5.

Illustration of turnpike theorem

When you are young, you behave as if you will live forever...



Application 1: Diminishing volatility

There is evidence that the volatility has a well pronounced time trend.

- Mc Connel and Pérez-Quiros (2000):
  – a *monotone* structural decline in the volatility of real GDP growth in the U.S. economy.
- Blanchard and Simon (2001):
  a *nonmonotone* pattern of the decline in the U.S. GDP volatility: there was a steady decline in the volatility from the 1950s to 1970, then there was a stationary pattern and finally, there was another decline in the late 1980s and the 1990s.
- Stock and Watson (2003):
  a *sharp reduction* in volatility of U.S. GDP growth in the first quarter of 1984.
- This kind of evidence cannot be reconciled in a model in which stochastic volatility follows a standard AR(1) process with stationary transitions.

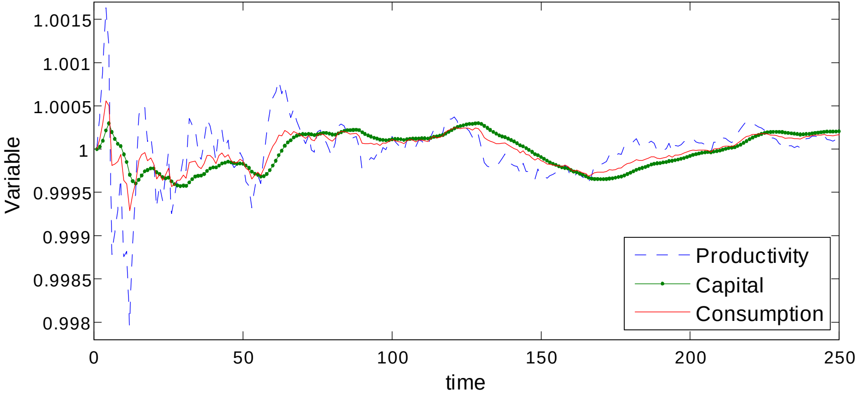
Application 1: Diminishing volatility (cont.)

- We consider a model in which the volatility has both a stochastic and deterministic components.
- We modify the standard neoclassical stochastic growth model to include a diminishing volatility of the productivity shock:

$$\ln z_t = \rho \ln z_{t-1} + \sigma_t \varepsilon_t, \qquad \sigma_t = \frac{B}{t^{\rho_\sigma}}, \quad \varepsilon_t \sim \mathcal{N}(0,1),$$

  – B = a scaling parameter;
  – ρ_σ = a parameter that governs the volatility of z_t.
- The standard deviation of the productivity shock $B\sigma / t^{\rho_\sigma}$ decreases over time, reaching zero in the limit, $\lim_{t\to\infty} \frac{B\sigma}{t^{\rho_\sigma}} = 0$.

Application 1: Diminishing volatility (cont.)



Application 2: Calibrating a growth model with a parameter drift to unbalanced U.S. data

- We took macroeconomic data on the U.S. economy from the webpages of the Bureau of Economic Analysis and the Federal Reserve Bank of St. Louis.
- The sample spans over the period 1964:Q1 - 2011:Q4.
- While the constructed data are grossly consistent with Kaldor's (1961) facts, we still observe visible differences in growth rates across variables.
- We do not test whether or not such differences in growth rates are statistically significant but formulate and estimate an unbalanced growth model in which different variables can grow at differing rates.

The model with a depreciation rate drift

We extend the benchmark model to include time-varying depreciation rate of capital,

$$\max_{\{c_t,k_{t+1}\}_{t=0,\ldots,\infty}} E_0 \sum_{t=0}^{\infty} \beta^t u(c_t)$$

$$\text{s.t. } c_t + k_{t+1} = A_t z_t k_t^{\alpha} + (1 - d_t \delta_t) k_t,$$

$$\ln \delta_t = \rho_\delta \ln \delta_{t-1} + \varepsilon_{\delta,t}, \qquad \varepsilon_{\delta,t} \sim \mathcal{N}\left(0, \sigma^2_{\varepsilon_d}\right),$$

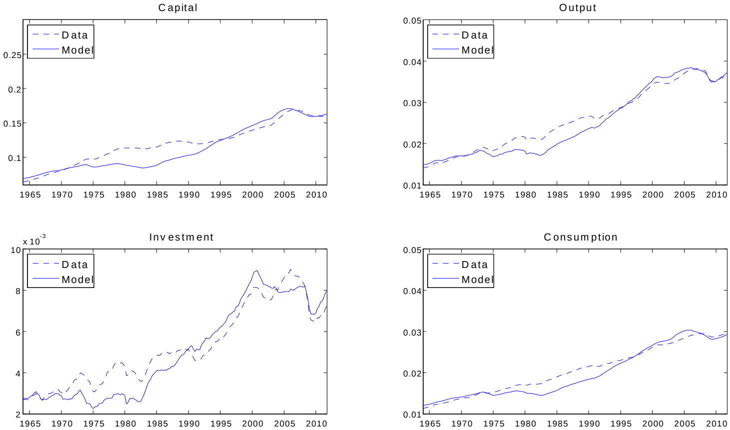
$$\ln z_t = \rho_z \ln z_{t-1} + \varepsilon_{z,t}, \qquad \varepsilon_{z,t} \sim \mathcal{N}\left(0, \sigma^2_{\varepsilon_z}\right),$$

$d_t \delta_t$ = a time-varying depreciation rate; d_t = a trend component of depreciation, $d_t = d_0 g_d^t$; δ_t = a stochastic shock to depreciation.

The model with a depreciation-rate drift

- Our assumption of a time trend in depreciation rate is consistent with the data of the Bureau of Economic Analysis.
- The aggregate depreciation rate changes over time because the composition of aggregate capital changes over time even if depreciation rates of each type of capital are constant; see Karabarbounis and Brent (2014).
- In turn, shocks to depreciation rate can result from the economic obsolescence of capital and are studied in, e.g., Liu, Waggoner and Zha (2011) and Gourio (2012).
- Gourio (2012) argues that a shock to the capital depreciation rate plays an important role in accounting for the business cycle fluctuations.

Fitted time series



Conclusion

- **An excellent paper:**
  – documented many new interesting empirical regularities on changing business cycles;
  – their theory is consistent with their empirical regularities;
  – explain economic mechanisms behind the changes in patterns;
  – provide supportive evidence of mechanisms.
- The model describes well the average behavior of comovement across all sectors.
  – the model's R^2 is 52%!
- Future work might address the arbitrariness of the cut-off period (i.e., 1984) and analyze a fully nonstationary RBC model.